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(54) Schottky diode for an integrated circuit

(57) A Schottky diode comprises a buried layer which has been produced by doping with two dopants, e.g. antimony and phosphorous, having different rates of diffusion. When a layer 2 is formed above the buried layer by high temperature episaxial growth the greater diffusivity of the phosphorous creates an outer region 10 containing phosphorous only as dopant surrounding an inner region 5 containing both dopants. This structure reduces the majority carrier resistance under forward bias and the leakage current to the substrate 3.

Fig. 2

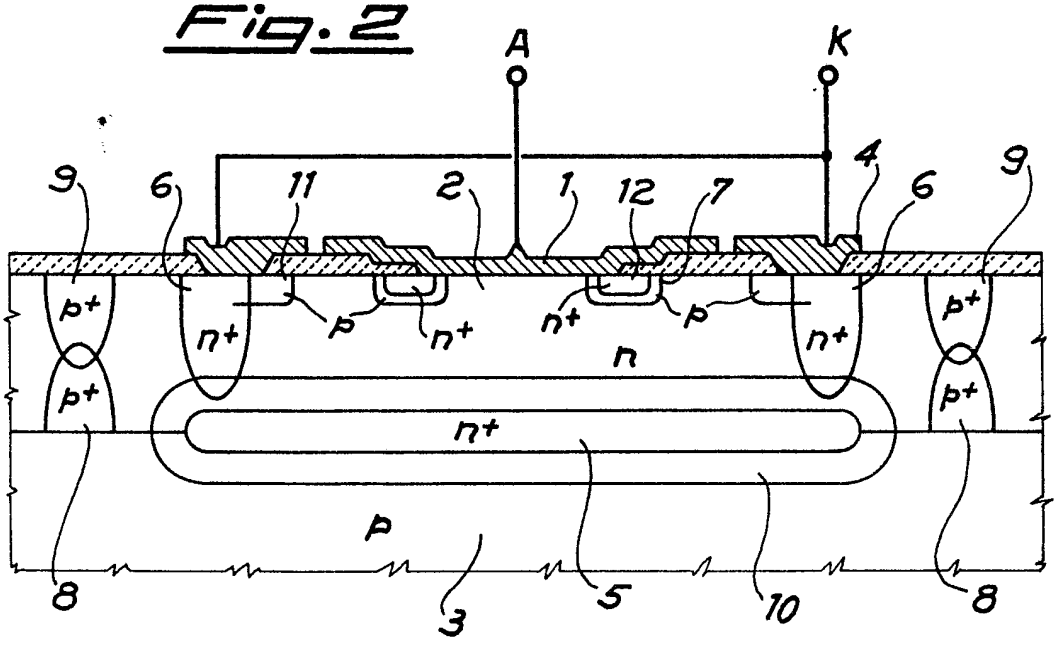

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Fig. 1

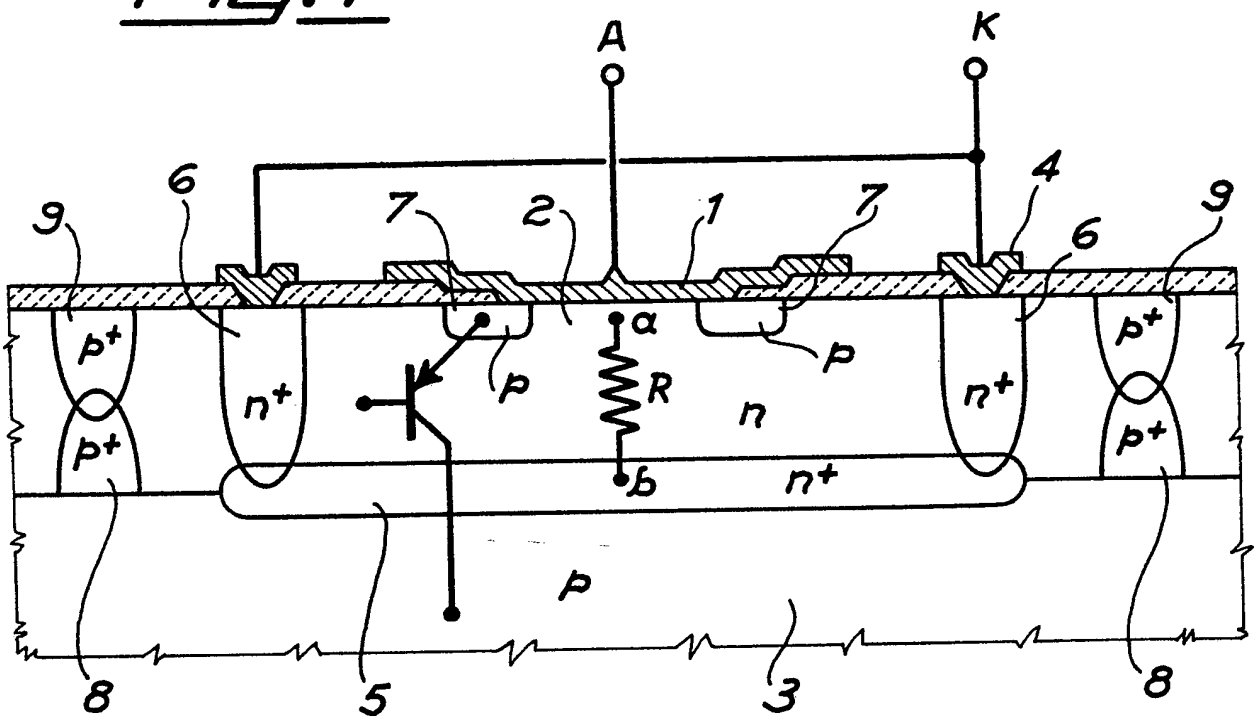
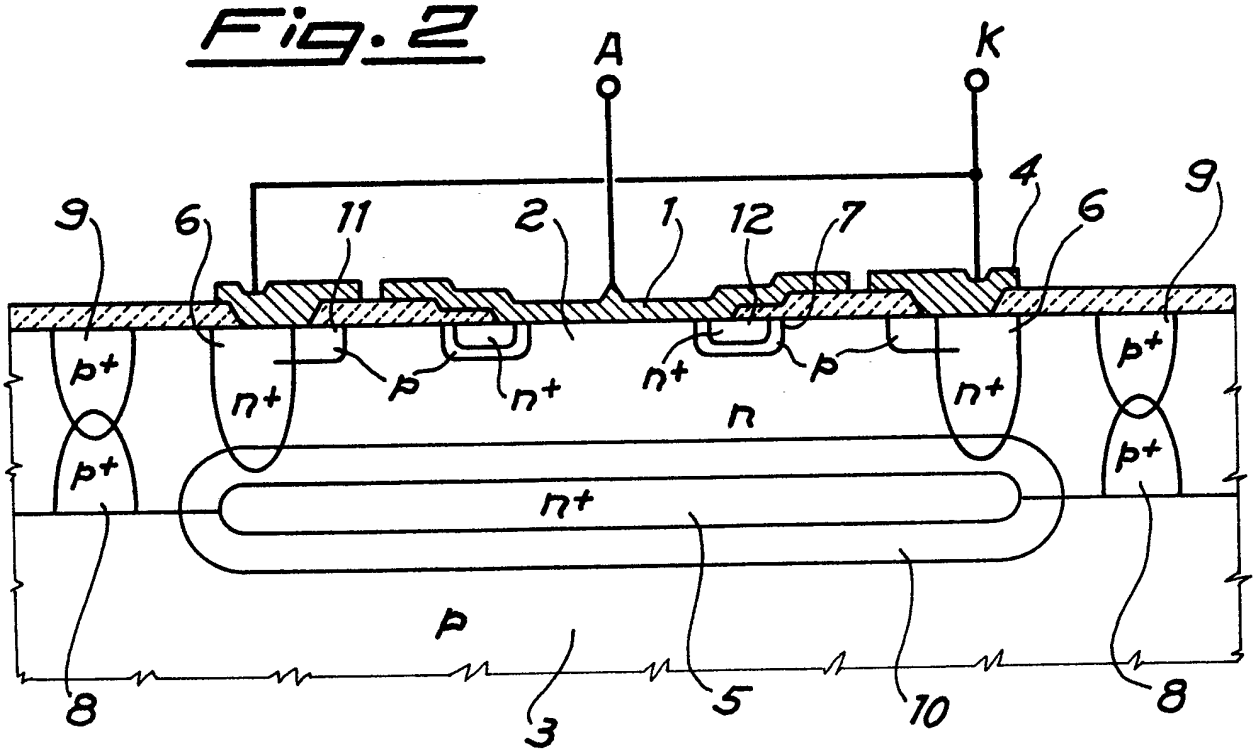


Fig. 2



SPECIFICATION

Integrated Schottky Diode

The present invention relates to an integrated Schottky diode having an improved structure such to reduce the forward voltage drop and to reduce also the leakage current towards the substrate during forward biasing of the diode.

Schottky diodes have had, and still have, a great importance in improving performances of integrated bipolar circuits, especially for digital applications that is switching applications, as well as for applications wherein extremely high frequencies are encountered such as for example microwave mixers and detectors, etc..

The Schottky barrier diode, that is of the rectifying metal-semiconductor junction type, possesses inherent characteristics which makes it much more advantageous with respect to the p-n junction diode in applications requiring high current density for the same direct voltage applied as well as in high frequency applications and in switching circuits.

In Schottky diodes, in fact, the current is attributable mainly to the majority carriers, while in p-n junctions minority carriers do contribute, and since the switching time of a p-n junction is limited by the excess of minority carriers, Schottky diodes have a decisively better behaviour at high frequencies. Moreover, in Schottky diodes, the forward voltage drop is very much smaller than in a p-n junction diode for the same current density (by at least an order of magnitude) and also this characteristic is advantageously exploited in different circuit applications of Schottky diodes. This latter characteristic of Schottky diodes makes them particularly effective in applications which contemplate operation at relatively high levels of return and thus extremely useful in power monolithic integrated circuits with currents commonly greater than about 0,5 A and wherein current levels of about 3—5 A are often reached.

An application of this kind is, for example, that of the recirculation diodes in transistors bridge output stages for driving electric motors or more generally inductive loads.

The physical implementation structure of Schottky diodes in integrated circuits has been more and more perfected with the aim of improving the diode characteristics.

It is known in particular that the structure of an integrated Schottky diode may comprise some expedients directed to reducing the probability of soft breakdown in the reverse characteristic of the diode. It is typical enough for the integrated structure to comprise the so-called "guard ring" consisting in a shallow p-n junction diffused along the edges of the contact area between the metal and the semiconductor and whose doping level is such as to give rise to a breakdown voltage higher than the one of the Schottky diode (planar contact area between the metal and the semiconductor).

Another well known expedient for eliminating the effects of soft breakdown consists in extending the metal layer over the oxide around the area of the Schottky barrier; under reverse bias the surface of the underlying semiconductor results depleted thus increasing the overall radius of curvature in the depletion zone of the metal-semiconductor contact.

A negative characteristic of integrated Schottky diodes described above is, as it is well known, constituted by the fact that, under forward bias conditions, there exists a parasitic PNP transistor giving rise to a certain leakage current towards the substrate.

A main objective of the present invention is to provide an integrated Schottky diode with improved characteristics of forward voltage drop.

It is a further objective of the present invention to provide an integrated Schottky diode with improved characteristics of leakage towards the substrate under forward bias conditions.

It has been found that, by providing a kind of "bottom-n-well" of appropriate dimensions (i.e. a phosphorus buried layer), that is a phosphorus-doped region around the actual buried layer of antimony, connected through a contact deep diffused region to the metallization of the cathode terminal, the voltage drop is significantly reduced in so far shortened results the resistive path made by the majority carriers injected at the metal-semiconductor contact. Simultaneously, by increasing the charge in the base region that is the total number of impurities per unity of area of the base region of the parasitic PNP transistor its intrinsic gain is reduced and therefore the characteristics of leakage toward the substrate of the integrated diode are decisively improved.

The "efficiency" of the parasitic PNP transistor may be diminished further by reducing the charge in the emitter region by diffusing, for example in the guard ring of the Schottky diode of p-doped silicon, a n^+ emitter region short-circuited to the p region.

Furthermore, we prefer substituting to the normal diffusion process for realizing the guard ring of the Schottky diode an appropriate boron implantation with the aim of obtaining the p-silicon region of the guard ring with a relatively high surface resistivity, e.g. about 0.5—1.0 KΩ/□, and having the desired depth because also this expedient has revealed itself useful in reducing further the charge in the emitter region of the parasitic PNP transistor.

Also with the purpose of reducing the leakage current towards the substrate, it is advantageous to form a further p-doped silicon region short-circuited to the cathode terminal of the diode in such a way as to form a lateral PNP transistor which is capable of recovering a portion of the current which otherwise would result in being injected towards the substrate under forward bias conditions of the Schottky diode.

With the aim of making the invention more easily understood the description will now proceed making reference to the annexed drawing wherein:

Figure 1 is an illustration of a vertical section of a conventional type of integrated Schottky diode; and

Figure 2 is an illustration of a vertical section of an integrated Schottky diode made in accordance with the present invention.

As it may be observed in Fig. 1, an integrated Schottky diode of the conventional type presents a section wherein it is easily identified the metallic

layer 1 acting as the anode A. The Schottky barrier is formed by the junction between the metal 1 and the semiconductor, e.g. n-silicon, of epitaxial layer 2 grown on a substrate 3 of p-silicon. The electric contact with the metallic layer 4 of the cathode terminal K is formed by the buried layer 5 of n^+ silicon and by the n^+ contact diffusion 6. The guard ring 7 is formed by the p diffusion, electrically in contact with the anode 1, formed along the perimeter of the rectifying (Schottky barrier) metal/semiconductor contact area.

Generally the characteristics of the different regions are the following: the buried layer 5 is silicon doped with antimony having a surface resistivity comprised between 10 and 30 Ω/□, the contact deep diffused region 6 is silicon doped with phosphorus having a surface resistivity of about 1 Ω/□ while the guard ring diffused region 7 is silicon doped with boron and having a surface resistivity comprised between 100 and 200 Ω/□.

The integrated structure is moreover, substantially isolated from other adjacent integrated components by means of the isolation p^+ deep diffused regions 8 and 9 of silicon doped with boron and having a surface resistivity comprised between 1 and 10 Ω/□.

Evidenced in a schematic manner in Fig. 1 is the parasitic PNP transistor which is excited under conditions of forward bias of the integrated Schottky diode giving rise to a leakage current towards the substrate. The emitter being represented by the p-region of the guard ring 7, the base by the epitaxial n-layer of silicon 2 and the collector by the p-silicon substrate 3.

In Fig. 2 is illustrated the cross section of an integrated Schottky diode made in accordance with the present invention wherein the regions or portions equivalent to the regions or portions of Fig. 1 are indicated by the same numbers and/or symbols.

As it may be observed, during the epitaxial growth a bottom-n-well 10 is formed that is a buried layer of silicon doped with phosphorus and having a resistivity of less than 60 Ω/□, around the actual buried layer of antimony 5 itself.

Since the forward voltage drop across the diode is essentially due to the resistance R of the path of the majority carriers from the depletion region, underlying the metal-semiconductor junction, to the cathode terminal, as schematically indicated in Fig. 1 by virtue of the phosphorus buried layer 10 a substantial reduction of such a resistance R is achieved.

Furthermore, by virtue of the phosphorus buried layer 10, the charge in the base region is greatly increased, that is the total number of impurities per unit of area of the base region of the parasitic PNP transistor, thus depressing its gain and therefore the leakage current towards the substrate.

Preferably, moreover, a p-silicon region 11, doped with boron and having a resistivity comprised preferably between 100 and 200 Ω/□, is formed in such a way as to result short-circuited to the cathode terminal K of the diode. In this way a lateral PNP transistor is formed capable of recovering a portion of the current which otherwise would be injected towards the substrate under conditions of forward bias of the Schottky diode.

The efficiency of the parasitic PNP transistor, which determines the amount of leakage current towards the substrate, may be further diminished by reducing the charge in the emitter region by forming a n^+ silicon region 12 within the guard ring 7 by diffusing phosphorus in such a way as to obtain a resistivity of about 4—6 Ω/□ or by increasing the resistivity in the p-silicon region of the guard ring to about 0.5—1 kΩ/□, utilizing an implantation technique for making the boron diffusion.

The sequence of the significant operations of the process of fabrication of an integrated Schottky diode of the invention starting from a normal p-silicon substrate may be synthetically described as follows:

1. Sb implantation for forming the inner buried layer (5);
2. P implantation for forming the outer phosphorus buried layer (that is the bottom-n-well) (10);
3. B implantation for forming the bottom isolation diffusion (8);
4. Epitaxial growth;
5. Deposition and diffusion of the isolation (9);
6. Deposition and diffusion of the contact (6);
7. Implantation or deposition and diffusion of the guard ring (7) and of the p-silicon region (11);
8. Deposition and diffusion of the n^+ silicon region (12) in the guard ring;
9. Opening of the contacts and metallization.

As it is well known to the expert technician, having implanted the pre-determined amount of Sb and of P on the appropriate area of the surface of the substrate, during the epitaxial growth which takes place at high temperature, typically at about 1200°C in the case of silicon, by virtue of the greater diffusion coefficient of phosphorus with respect to the one of antimony, phosphorus diffuses for a greater "depth" than antimony. The two buried layers are thus formed of antimony and phosphorus in an inner region and essentially of only phosphorus in an outer region. This is, on the other hand, the technique utilized for making the so-called "bottom-n-well" in the process of fabricating vertical PNP transistors with isolated collector. The fabrication process of the integrated Schottky diode of the invention may thus result of simple implementation within the general process of fabrication of the whole integrated circuit.

In the structure of the Schottky diode of the invention the buried layer of n^+ silicon doped with antimony constitutes a sort of "core" of high conductivity of the composite structure for the electric contact with the cathode terminal thus contributing, by virtue of its high conductivity, to reduce the transverse resistance of the composite contact structure which comprises the outer phosphorus buried layer 10 and the contact diffusion 6 besides, naturally, the inner antimony buried layer (5).

The Schottky diode of the invention is particularly effective in applications contemplating high current

density, for example, as recirculation diodes in transistors bridges for driving electric motors and/or inductive loads.

The modification introduced in the normal fabrication process determines a small decrease of the maximum reverse voltage sustainable by the Schottky diode of the invention which results substantially similar to the collector-emitter voltage of the NPN transistor with respect to the one of the conventional type Schottky diode which is potentially equivalent to the collector-base voltage of the NPN transistor. This small decrease is, on the other hand, negligeable in many applications such as the ones mentioned above, wherein, viceversa, the reduction of the forward voltage drop of the leakage current toward the substrate are very advantageous characteristics.

CLAIMS

1. An integrated Schottky diode formed in the epitaxial layer grown on a substrate and having a structure of electric contact with the cathode terminal comprising a buried layer and a deep contact diffused region reaching such buried layer characterized in that said structure of electric contact comprises a first buried layer and a second buried layer, the latter being realized with a dopant having a higher diffusivity of the diffusivity of the dopant of said first layer and extending itself for a larger depth than the depth of said first layer within the thickness of said epitaxial layer from the surface of said substrate.

2. The integrated Schottky diode of claim 1 wherein said deep contact diffused region extends as far as reaching at least said second buried layer.

3. The Schottky diode of claim 1 wherein said substrate is of p-silicon, said first buried layer is of n^+ silicon doped with antimony, said more extensive buried layer is n^+ silicon doped with phosphorus and said deep contact diffused region is n^+ silicon doped with phosphorus.

4. The Schottky diode according to claim 3 wherein the diode is provided with a guard ring and with a p-silicon diffused region doped with boron short-circuited with the cathode terminal of the diode formed along the edge of said deep contact diffused region opposed to said guard ring for forming a lateral PNP transistor.

5. The Schottky diode according to claim 4 wherein said guard ring is a region of p-silicon formed by boron implantation and diffusion and having a surface resistivity greater or equal to 0.5 $k\Omega/\square$.

6. An integrated Schottky diode substantially as described herein with reference to fig. 2 of the accompanying drawings.

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ABSTRACT:

CHG DATE=19990617 STATUS=O> A Schottky diode comprises a buried layer which has been produced by doping with two dopants, e.g. antimony and phosphorous, having different rates of diffusion. When a layer 2 is formed above the buried layer by high temperature episaxial growth the greater diffusivity of the phosphorous creates an outer region 10 containing phosphorous only as dopant surrounding an inner region 5 containing both dopants. This structure reduces the majority carrier resistance under forward bias

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